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# Augmented reality and mobile learning: the state of the art

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## ABSTRACT

In this paper, we examine the state of the art in augmented reality (AR) for mobile learning. Previous work in the field of mobile learning has included AR as a component of a wider toolkit for mobile learning but, to date, little has been done that discusses the phenomenon in detail or that examines its potential for learning, in a balanced fashion that identifies both positive and negative aspects of AR. We seek to provide a working definition of AR and examine how it is embedded within situated learning in outdoor settings. We also attempt to classify AR according to several key aspects (device/technology; mode of interaction; type of media involved; personal or shared experiences; if the experience is portable or static; and the learning activities/outcomes). We discuss the technical and pedagogical challenges presented by AR before looking at ways in which AR can be used for learning. Lastly, the paper looks ahead to what AR technologies may be on the horizon in the near future.

## Author Keywords

Augmented reality, mobile learning, education, situated learning, technology enhanced reality, state of the art, taxonomy.

## INTRODUCTION

Augmented reality (AR) is a growing phenomenon on mobile devices, reflected by the increase in mobile computing in recent years and the common ubiquity of Internet access across the world. The NMC Horizon Report for 2011 named augmented reality as the highest-rated topic by its Advisory Board, with widespread time-to-adoption being only two to three years (Johnson *et al.*, 2011). What was once seen by many as being a mere gimmick with few applications outside of training, marketing/PR or sport and entertainment, is now becoming more mainstream with real opportunities for it to be used for educational purposes.

This paper examines the state of the art in the application of augmented reality for education, with a particular focus on mobile learning that occurs in specific locations and outdoor settings. One of the most compelling affordances of AR is its resonance with immediate surroundings and the way in which information can be overlaid on top of these surroundings, enabling us not only to learn about our environment but also giving us the tools to annotate it.

The paper begins with a definition of what we mean by augmented reality, before then exploring the pedagogical theories that underpin AR. We offer a framework that can be used to classify AR in mobile learning, before examining the criticisms and limitations of AR. Lastly, we suggest how AR can be embedded within mobile learning. We make two important contributions to the field: firstly, a *discussion of the underlying pedagogies* surrounding the use of AR; and secondly the *taxonomy* that seeks to classify the different aspects of mobile AR for learning in outdoor situations.

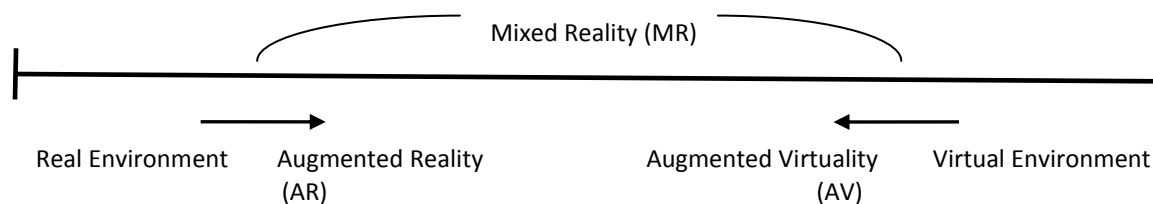
## DEFINING TECHNOLOGY ENHANCED REALITIES: VIRTUAL, MIXED AND AUGMENTED

Azuma (1997) defined AR as “3-D virtual objects [...] integrated into a 3-D real environment in real time” and this reflects the majority of early research into the use of AR as a primarily graphical display. However we consider this definition to be too narrow and instead prefer to consider a working definition of AR to include the fusion of any digital information within real world settings, i.e. being able to augment one’s immediate surroundings with electronic data or information, in a variety of media formats that include not only visual/graphic media but also text, audio, video and haptic overlays. Indeed, in a later paper, Azuma *et al.* (2001) updated this earlier definition and reduced the emphasis on graphical objects, stating that the three essential properties of AR are the combination of virtual and real objects in a real environment; a system that aligns/registers virtual and real objects with each other; and that runs interactively in real time. They also mention ‘mediated reality’ or ‘diminished reality’, where real objects in the user’s surroundings are electronically stripped out or removed, so the user is better able to focus on other aspects of their environment.

A critical aspect of AR is the *context* in which it is used: it is not just enough to state that AR is mere availability or presence of digital media within a particular location, as this could encompass a casual passer-by listening to music on their mp3 player as they travel through that environment. Rather, we need to take into account the *explicit intention* of this digital media, to supplement or augment our surroundings through additional information being made available (e.g. visually, auditory or through haptic interfaces) that has contextual relevance to that specific place.

Milgram *et al* (1994) provide a helpful visualisation to represent how reality and virtuality are connected (see Figure 1). It shows a continuum that encompasses all real and virtual objects and environments. Mixed reality is an area in the

middle, where the two extremes meet, and is considered a blend of both the virtual and the real:



**Figure 1: Representation of the Reality-Virtuality (RV) Continuum, re-drawn from Milgram *et al.*, 1994**

Whilst it is clear that virtual, as well as real, environments can be augmented, this falls under the category of ‘augmented virtuality’ as shown in Figure 1 and as such is outside of the scope of this paper. Much interesting work has been done in the area of virtual worlds and education; however we are more concerned with how learning takes place in an augmented *real* world. We will also be focusing on the use of augmented reality for mobile learning, in all senses of the word ‘mobile’, where the learner is not constrained to a desktop PC at a fixed location and the learning itself may be dynamic and across contexts. Fixed or static AR can be seen more in large screen displays in public spaces or through desktop computers and can generally only be used in that one specific place. Mobile AR brings in new aspects: most importantly, it fosters the mobility of the user; their geographical position; the physical place where learning can occur (and also a means to bridge these different places); it can also enable formal learning to connect with informal learning. It also serves as a mechanism for more personal or individual experiences with AR, as shown later in Table 1, compared to a large static display that may be more suited to group experiences (such as those used for marketing or advertising). Spatial mobility is a powerful component in its own right, although it could also be combined with temporal mobility to bring AR to a new dimension, so learners can take advantage of AR resources ‘on-the-fly’, at a time and place convenient and relevant to them. Mobile AR enables us to integrate real-world experience and meaning within specific physical contexts.

In addition, most of the AR examples we discuss are located in outdoor environments; this is merely a reflection of the research in this area and is not an indication that AR should only be used outside, only that it seems compelling and easy to do so (possibly due to current technical limitations in indoor tracking/positioning, as a learner’s location is often an integral aspect of the AR experience). In the past, technological limitations have sometimes confined both AR devices and their users to a fixed location; however developers have always aimed to make AR portable. When Sutherland began work on a three-dimension headset display in the 1960s, he noted that the fundamental idea behind such a display was “*to present the user with a perspective image which changes as he moves*” (Sutherland, 1968). Azuma (1997), considering the state of the art in AR, looked back on a decade of literature dealing with the medical, manufacturing, visualisation, path planning, entertainment and military applications of AR. His review suggests various learning opportunities implicit in this research, such as the opportunity for medical students to develop their understanding based on an X-ray view of the human body, or for trainee architects to see not only the structure of buildings, but also their underlying infrastructure. He identified factors that would be key to the mobility or portability of this technology; also the need for trackers or sensors that could support the accurate alignment of physical and virtual realities at a distance by providing greater input variety and bandwidth, higher accuracy and longer range.

The developments Azuma reported in 1997 focused mainly on adding visual information, but by the beginning of the twenty-first century, researchers were working on augmented reality for all senses, including hearing, touch and smell (Azuma *et al.*, 2001). Milgram and Kishino (1994) wrote of the possibilities for *auditory* augmented reality, mixing computer-generated signals with those from the immediate real-world environment; *haptic* augmented reality, incorporating artificially generated sensations of touch and pressure; and *vestibular* augmented reality, synthesising information about the forces of acceleration acting on its user. Possibilities for mobile applications were also increasing, as researchers worked to make use of situational awareness and geolocated information retrieval. For example, Columbia University’s Mobile Augmented Reality System (MARS) combined a mobile computer and headset with a compass, inclinometer and GPS (Global Positioning Systems), allowing users to see representations of historical buildings in their original locations (Höllerer *et al.*, 1999).

Other examples include Robinson *et al.* (2008), who developed a point-to-select method for GPS and sensor-equipped mobile devices, allowing users to highlight locations of interest during a journey and to later view a report about these locations. Kanjo *et al.* (2008) developed ‘MobGeoSen’ software components using sensors in mobile devices for mobile data collection to monitor the local environment or record a persons’ activities. Further research by Benford *et al.* (2004) has evaluated systems for location-based multi-player games, seeking to understand how *in situ* users share location information at a distance through comparing self-reporting and GPS readings. Finally Coulton *et al.*’s (2010) recent work combines the emergent activity of geocaching (an activity similar to a GPS-guided treasure hunt) with augmented reality.

Mobile learning research has long understood the importance of locational context and the objects found in that location, to the process of meaning-making (Clough, 2010; Leinhardt *et al.*, 2002) and over recent years the capabilities of location-aware technologies has dramatically increased. Combining GPS and digital compass technologies can provide a basic functionality for locating someone holding a device and computing their orientation within that environment.

Recent advancement in GPS and networks have now enabled location accuracy to within 5-10 metres for single-point receivers (Ordnance Survey, 2012); with carrier positioning accuracy (or 'survey grade GPS'), this can be improved to less than 1 centimetre. Larger, thinner and lighter touch-sensitive screens and advances in cameras and sensors also increase the potential for creating and viewing information anytime and anywhere. Combining these technologies has led to the recent emergence of mobile applications that utilise location sensing to provide users with relevant geo-referenced information. Smartphone apps, such as Wikitude and Layar, orient users to information about their surrounding area (e.g. approximate distance and direction to a point of interest). What these systems need now are appropriate visualisations (or other methods of feedback), representations and guidance to provide or enhance *situated* meaning-making.

### **AUGMENTED REALITY, SITUATED LEARNING AND EMBODIMENT**

In order to gain insights into the unique learning affordances of mobile AR, we need to juxtapose it with mobile learning in 'normal' (and thus non-augmented) reality. But what is 'normal reality' mobile learning before we augment it and what does augmenting that reality provide us with? A focus on learning through interaction with 'reality' directs us to situated theories of learning, and a careful attention to context. Indeed, e-learning designers, developers and educators often lack clarity regarding the impact that a student's situation has on their interpretation of e-learning. Vygotsky argued that human consciousness is associated with the use of tools and artefacts, which mediate contact with the world. These tools produce quantitative improvements in terms of the speed and efficiency of human development; they also produce qualitative transformation because mediated contact with the world provides humans with the means to control and organise their behaviour rather than be buffeted by external stimuli (Vygotsky, 1978). Vygotsky's emphasis on the mediating role of artefacts introduces the material dimension of reality, or context, yet limits that to man-made objects, excluding the natural world. Arguably, any material object we interact with is artificial, in the sense that our perception of that object is shaped by culture and history. However, Bruner (1990) and Papert and Harel (1991) broaden the lens, and consider the child's development through exploratory interaction with the world around them and abstraction of their experiences.

Bowker and Star (2000) take the concept of 'situated' learning further by suggesting we must also consider issues of space and time in a learning process, although this could increase the potential for chaos. Latour (1999) in turn emphasises our need to create order in these processes and the increased likelihood of disorder elsewhere. Education, it could be argued, often involves widening the gap between these worlds before some resolution is made. Our 'reality' is therefore continually mediated and reinterpreted by our practices and meaning-making exercises in that reality. At a first glance, the shift from low-tech to mobile-tech and to AR may seem merely quantitative: augmenting, or rather *adding* to that reality has always been a part of education, whether it is through e.g. informative signposts placed at a geological site or tourist venue; costumed re-enactments of historical events; or a straightforward on-site tuition provided by a teacher or parent. We change our perspectives, understanding and meaning-making of that reality through augmenting it with additional educational information. Technology has merely given us systems and resources that can enhance our situated learning through augmenting our realities more effectively. Yet we need to consider how new technologies might offer the potential for qualitative change in our relationship with reality: imagine a learner leaving a 'video note' for her peers at a historical point of interest; viewing a geographical site as it would have looked in the ice age; or collecting audio-visual notes of her observations. Such experiences transform reality into a multi-modal social text, in the tradition of Bezemer and Kress (2008).

Embodied cognition can also provide us with a complementary framework, since AR affects the way we interact with the physical world. The bodily experiences that we engage with when we use AR, help us to construct meanings from our reality and include cultural and contextual factors, as well as social ones – hence cognition itself is embodied (Núñez *et al.*, 1999; Radford, 2005), providing a foundation for social situatedness. Barab *et al.* also refer to 'situative embodiment' (Barab *et al.*, 2007) where the learner "*enters into a situation narratively and perceptually, has a goal, has a legitimate role, and engages in actions that have consequence*".

### **CLASSIFYING AUGMENTED REALITY: A SUGGESTED TAXONOMY**

This section of the paper aims to produce an initial taxonomy of projects where AR has been used in mobile learning scenarios; a wider taxonomy could also include purpose/usage as a separate category, where education would be one example (others might include providing information; navigation; entertainment; social interaction; marketing/PR etc). However, for the purposes of this paper we focus on education, specifically mobile learning, examining first the different dimensions inherent in AR before exploring some of these in more detail through several case studies.

Table 1 shows the different dimensions used in six mobile learning projects that used augmented reality as a key component. The information displayed in this table shows how AR has been used mostly as a portable experience, but which lends itself to both personal and shared interactions. There were no incidences of larger, static displays or ones targeted at larger group experiences, both attributes which are exemplified in AR experiences such as video mapping (see e.g. work by the Macula project, such as 'old town' [<http://vimeo.com/15749093>], created to celebrate the 600 year anniversary of the astronomical tower clock situated at Old Town Square in centre of Prague). This may suggest that the current use of AR in mobile learning is generally geared towards individual (or small group) experiences.

Project (in date order)	Device or technology used	Mode of interaction	Method of sensory feedback to the user	Personal or shared experience	Fixed/static or portable experience	Learning activities or outcomes
Zapp (Meek <i>et al.</i> , 2012)	Smartphone	Passive/assimilative (information layer) + active/exploratory (data logging/querying tool)	Visual overlay: label/text	Both personal and shared (small groups)	Portable	Interpreting the geological features of a rural landscape through situated inquiry and collaboration
Out There, In Here (Adams <i>et al.</i> , 2011)	Laptops, tablet devices, smartphones	Passive/assimilative (information layer) + exploratory	Mixed: visual; auditory; text	Shared (small groups)	Portable	Collaborative inquiry-based learning, to enable sharing of data; development of hypotheses; access to information/resources etc. between in-field students and those indoors in a lab
CONTSENS (Cook, 2010)	PDA (Personal Digital Assistant); mobile phones	Constructionist (AR- based modelling)	Mixed: visual (3D wireframe model); video	Both personal and shared between 2 users	Portable	Archaeological and architectural surveying of the ruins of an abbey; specifically, providing different visual perspectives on the mobile devices
Augmenting the Visitor Experience (Priestnall <i>et al.</i> , 2010)	PDAs; mobile phones; tablet devices; head- up display (HUD)	Passive/assimilative (information layer) + active/exploratory	Mixed: visual, audio, text, video	Both personal and shared between 2- 3 users	Both static and portable	Comparing different technologies/techniques to provide information about the landscape to the casual visitor; student-generated criteria focused upon usability and sustainability
History Unwired (Epstein and Vergani, 2006)	Smartphones, PDAs (Pocket PC) + headphones	Passive/assimilative (information layer) + active/exploratory	Mixed: audio, video	Both personal and shared	Portable	Informal learning about the Castello region of Venice, via a walking tour that uses local citizens to depict a local experiences of art and craft, history and folklore, public and private spaces
Mudlarking in Deptford (Futurelab, 2006)	PDAs + headphones	Passive/assimilative (information layer) + active/exploratory	Mixed: text; audio; visual	Shared (small groups + pairs)	Portable	Students acted as co-designers to help create local tour guides on mobile devices, using multimedia relating to the local area and their own observations

**Table 1. A suggested taxonomy of AR used in mobile learning projects, showing how it can be used to categorise different aspects of the research**

The modes of interaction have generally focused around either providing passive information overlays to the learner, depending on their physical location or movements/gestures, or engaging the learner in an exploratory mode where they are encouraged to actively discover or create/log media nearby in order to e.g. solve a problem or meet characters from a story. More modes of interaction may evolve in the future although some, such as the ‘constructionist’ mode, may be more relevant to specific knowledge domains (e.g. architecture or structural engineering). The ‘active/exploratory’ mode is also akin to AR games such as Environmental Detectives (Klopfer and Squire, 2008), although we have concentrated on non-gaming examples here as this is another research area in its own right.

The media used has primarily been a mixture of visual (still images), video, audio and text, although the ‘Augmenting the Visitor Experience’ project also used a non-digital format, that of printed acetates showing an outline of the landscape at fixed viewpoints with written annotations/labels. Whilst this is not strictly AR, according to our earlier definitions, it nevertheless presents an interesting vision for the future, as its transparent properties mean that information can be overlaid whilst the user is still able to literally see beyond the augmentation and still perceive the landscape behind it. This property is being exploited by Google with their ‘Google Glass’ product, that is discussed later in this paper. It is interesting to see how the nature of the device or technology used for engaging with AR has also changed; early projects tended towards the use of PDAs and mobile phones, whereas more recent projects are, not surprisingly, utilising smartphones and tablet devices. What is exciting is how personal smartphones contain an increasingly sophisticated array of sensors, thus enabling AR to become more personally meaningful and situated, so that what was once the domain of a

researcher intervention loaning specialist equipment for a short user trial, is now much more likely to be accessible by the students or the general public on an everyday basis, thus providing a more sustainable technology for everyday learning.

## **CRITICISMS AND LIMITATIONS OF AUGMENTED REALITY**

Although AR as a technology has evolved much over the last decade, there remain some challenges and limitations around the use of AR in educational situations. These can be broadly divided into technical challenges and pedagogical challenges.

### **Technical challenges**

While high cost, fragile geolocation systems can measure to centimetre accuracy, handheld mobile tools accessible to the wider educational sphere can only measure to several metres accuracy (e.g. handheld GPS receivers, or mobile devices containing such). The accuracy of such devices can be further degraded by local environmental conditions, such as 'urban canyons', where tall buildings create shadowing and reflecting of signals to further lower the ability of a student to pinpoint their position. Practically, this means that educational settings can only expect accuracy to within ten metres: suitable for standing on top of a mountain and surveying a large area, but not to distinguish one side of a street from another (Gaved *et al.*, 2010). A lack of accuracy in pinpointing a student's position may lead to registration errors, where an AR device or app, retrieving data from a recorded set to match what it thinks is the device's present location, may present wrong information to the student as it is unable to correctly calculate its exact position.

AR typically requires some form of internet access. Devices using phone networks will be susceptible to varying quality of signal: while basic phone and 2G networks may be reliable in urban areas in developed countries, rural and less developed locations may have less reliable signal quality. Additionally, 3G and other higher data rate services cannot be assured: for example, there is greater 3G phone coverage by area in the seas off Scotland, than on the actual mainland of Scotland (Ofcom, 2009). Alternative strategies, such as setting up your own local network, may have to be considered if reliable network access is required for the tools to function (Davies *et al.*, 2010).

In common with other mobile technological tools, the student and tutor have to maintain the overhead required for the devices to function: battery life may become an issue, as can finding locations where good radio signals can be picked up. Other concerns include ensuring the screen can be read in bright sunlight and ensuring the device can function in rain, or after being dropped.

### **Pedagogical challenges**

AR can present many pedagogical issues in common with other technological additions to learning and teaching. One criticism of AR is the concern that learning may not be driven by the pedagogy but more by the AR tools' strengths and weaknesses.

For example, the novelty of the technology may detract from the learning experience (e.g. students focussing on shiny new devices rather than their learning objectives). The technology may also guide how and where the learning occurs and it is important to make sure the learning is not altered to fit around the device's limitations (e.g. do students need to work where there is a shaded area so they can see the screen, rather than standing in the best place to understand the context; do educators need to factor in extra time to change batteries and hence there is a reduction in the amount of time spent actually being physically in location). There may also be a need for additional technical support if the AR is not easy to use and install.

There is also the problem of the technology being more engaging than the surrounding environment and instead of making the most of being at a particular location, students' attention is inappropriately focused on the AR devices and tools. In this situation, it is important to consider if the technology actually removes the students from the immediate experience of the location rather than augmenting it.

From a teaching perspective, it is also critical to consider first what are the learning objectives and goals that a tutor or educator wants their students to achieve, before considering how best to achieve these. It may be that AR is not the best method to employ and that other, cheaper, more robust techniques are much more appropriate to the learning activity that is taking place. Additionally, providing an immediate overlay of labels on e.g. geographic/architectural features could possibly lead to a detriment in developing observation skills through excessive scaffolding and reinforcing. In this situation, it may be better to offer a more staged approach where AR is offered as an add-on, once students have acquired a certain level of proficiency in interpreting their environment without needing the use of such tools.

## **EMBEDDING AUGMENTED REALITY IN MOBILE LEARNING: PRESENT AND FUTURE**

It is clear that there are both opportunities and challenges in integrating AR into mobile learning; however we remain convinced that there is something very compelling in doing so. Studies have shown that using AR for educational purposes can appeal to students at a much more personal level, promoting both engagement and motivation amongst its users (Klopfer and Squire, 2008; Luckin and Stanton Fraser, 2011). A recent study where AR was used in a static environment, using desktop computers both at school and home, showed that AR supported particular learning activities, such as problem solving, in a highly interactive and memorable fashion (Luckin and Stanton Fraser, 2011). This last study also referred to other positive aspects of AR found within its research, such as its ease of use amongst young children; its enjoyment/"fun" factor; its flexibility (in terms of using it with a range of age groups or across different

subject domains); the ease of use in reference to installation/mobility of hardware; and the immersive and engaging nature of three-dimensional AR visualisations (Luckin and Stanton Fraser, 2011).

Several projects have focused on the way in which AR can be used to encourage problem solving and independent research amongst learners. For example, Squire (2010) notes that *"from a classroom management perspective, the narrative elements of the unit enabled teachers to create a dramatically different classroom culture, one that was built around students performing as scientists. ... Most noteworthy to teachers was how the technology-enhanced curriculum enacted students' identities as problem solvers and knowledge builders rather than as compliant consumers of information..."*. The idea of learners engaging in collaborative problem solving has also been examined by Cook and his work on Augmented Contexts for Development (ACD) (Cook, 2010) that extends the original Vygotskyan concept of Zones of Proximal Development (ZPD) (Vygotsky, 1978). Cook suggests that mobile devices and their surrounding physical environment enable learners to generate their own contexts for development, which can be interpreted or assisted through AR. From the analysis of a video blog recorded by students on an architecture field trip, it seems that students used physical and digital representations to synchronously interact and inform one other, leading to a co-constructed knowledge that formed as a result of the interaction of the learners with the AR tools and media. In this respect, the mobile devices acted as contextual sensors, enabling particular visualisations to be portrayed to the learners in a situated manner. Another example of how situated visualisations and mobile connectivity to larger processors and server infrastructure can enable learning can be seen through translational overlays of AR, when viewing a foreign language text through e.g. smartphone apps.

Another way in which AR can be used to support learning is through haptic interfaces, particularly when used with blind or visually-impaired users. The 'Haptic Lotus' used a handheld plastic flower that contained embedded sensors that responded to its user position in an indoor gallery by opening its petals and delivering haptic feedback, and was used as a way of encouraging exploration whilst also providing reassurance of the nearby environment for both sighted and blind people (van der Linden *et al.*, 2012). Mehigan (2009) also discusses the use of sensors in smartphones – particularly accelerometers – to develop opportunities for mobile learning for vision-impaired students and also reduce the 'digital divide' that exists between sighted and blind students. Audio may also be a valuable AR tool here: for example, a sound-rendering system can transform the visual data of objects and places into auditory information, overcoming a major difficulty currently experienced by visually impaired learners. In addition, being able to integrate visual labels and audio tracks into learning environments offers teaching opportunities for all learners and may be particularly helpful for pupils with learning difficulties, whose cognitive abilities may not allow them to visualise abstract or hidden parts of systems (Lin *et al.*, 2012). Sprake also talks about haptic referencing as a means of connecting more fully with our local surroundings (Sprake, 2012).

The use of haptic referencing and the notion that embodiment in mobile learning can be facilitated by AR is an intriguing one. Becket and Morris (2001) argue that learning has become disconnected both physically and conceptually from the student and that educational research must return to the physicality of the students' bodies for two reasons: firstly, the growth of the corporatized virtual university (and thus a diminished importance attached to a physical place of study by corporate managers); and secondly the commoditisation and packaging of learning (digital content is placed online and "left to die" in a VLE - see timbuckteeth, 2011). Mobile learning where learning is situated, or *embodied* in a particular reality, which is itself augmented, could help to counteract these problems.

In the last decade, augmented reality has progressed from a specialist, relatively expensive technology to one that is now commonly available to the general public, due to technological advances in mobile computing and sensor integration. Although it could be argued that AR has yet to become completely mainstream, smartphone apps such as Layar and Wikitude mean that its adoption and use is becoming increasingly commonplace. Large corporations such as Google have shown its commitment in developing AR technology, e.g. through the Google Goggles product (visual recognition of landmarks in photos taken by e.g. a smartphone camera and subsequently overlaying relevant information) and more recently the Google Project Glass, a proposed 'heads-up display' that will overlay contextual information on top of clear transparent glass, through e.g. AR spectacles (Eddy, 2012). EyeTap uses a similar premise to Project Glass, with the device worn in front of the eye like a pair of conventional glasses, that can record what the wearer is seeing but also superimpose computer-generated imagery on top of their normal physical world (see <http://eyetap.org> for details).

One use of AR that will increasingly become available and promoted through Higher Education institutions builds on the campus map and providing navigation for newcomers (the 'augmented campus', see e.g. Genco *et al.*, 2005), as well as linking in with friendship circles to arrange common meet-up times and locations. This extends prior experiences of the use of mobile devices for more immediate use of 'dead time' (Pettit and Kukulska-Hulme, 2007). While this has previously been managed through plan views and mapping tied with social networks, overlays are increasingly used to convey this information, as can be seen by the recent advent of Blackboard Mobile Central AR features (Blackboard, 2012).

## SUMMARY

We have presented what we consider to be the current state of the art of augmented reality for mobile learning. We have discussed the theoretical underpinning of AR in relation to situated learning and created a taxonomy of AR mobile



learning projects as an interesting way of analysing current trends and exploring the potential for future development. We have also discussed the limitations and challenges inherent in the application of AR for mobile learning experiences, as well as offering some suggestions of how AR can enhance learning and how it might be used by students and educators.

The use of AR in education, and particularly mobile learning, is still in its infancy and it remains to be seen how useful it is for creating effective learning experiences. From examining the learning activities shown in Table 1, it is clear that AR can be used very successfully for situated and constructivist learning, particular where collaboration and student inquiry form key aspects. It can also be used for informal learning and more touristic experiences.

We hope to revisit this work in another few years and report on new innovations and the way in which they have been adopted (or not) by the learning community. What is clear is that we currently have the opportunity to provide immersive, compelling and engaging learning experiences through augmented reality, which are situated in real world contexts and can provide a unique and personal way of making sense of the world around us. We believe this is a powerful tool, provided we can harness it appropriately, and look forward to seeing how other academics and practitioners advance this research field further.

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